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ScienceDirect

Physics Procedia 74 (2015) 287 – 291

Physics Procedia

Conference of Fundamental Research and Particle Physics, 18-20 February 2015, Moscow, Russian Federation

The properties of the gamma-ray bursts with high-energy spectral component

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Abstract

Spectral properties of some GRB with presence of high-energy component are discussed. The energy spectra shape of GRBs with high energy emission presence can follows the Band model (or power law or broken power law) up to some tens or hundreds of MeV (as for GRB 100724B and GRB 021008) or contains additional high energy power law component (for example, GRB 050525B and GRB 090902B). Both GRBs types were registered since CGRO mission has begun. The analysis of their energy spectra has shown that the break between low energy spectral part (described by either Band or power law or broken power law etc. models) and additional component was in energy region 2 - 200 MeV. The Fermi/LAT low energy threshold is lower than CGRO/BATSE one and the very low-energy spectral component described by power law with index δ and characterised X-ray emission in the range E<50 keV was introduced for several bursts energy spectra approximation. Moreover, for several GRBs this spectral parameter δ similar to Γ (characterizing gamma-emission in the band E >100 MeV) and the question about formation of wide range emission during GRB due to single mechanism arises again.

Peer-review under responsibility of the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)

Keywords: GRBs high energy component, spectral breaks

1. Introduction

The previous results of gamma-ray bursts (GRB) observations were mainly obtained by the Compton Gamma Ray Observatory (CGRO) results analysis in both X-ray and gamma-ray energy bands simultaneously. Four

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Peer-review under responsibility of the National Research Nuclear University MEPhI (Moscow Engineering Physics Institute)
doi:10.1016/j.phpro.2015.09.241

experiments onboard CGRO: BATSE, OSSE, COMPTEL and EGRET [1] provided the energy range 10 keV–20 GeV for events observations. Gamma-quanta with energies $E\gamma>20$ MeV were first observed during GRB 910503 in 1991 [2]. CGRO operated since April 1991 up to June 2000 and more than 30 GRBs with high energy photon emission presence were registered - see, for example, [3]. Gamma-ray bursts duration is described by the time intervals of 90% and 50% event intensity registration (t_{90} and t_{50} correspondingly). Bursts duration distribution bimodal structure corresponds to GRBs separation into two classes: long bursts (t_{90} more than 2 s) and short ones (t_{90} less than 2 s) [4].

After CGRO GRBs observations in the high energy gamma-band provided by AVS-F apparatus onboard Russian satellite CORONAS-F (NORAD catalogue number 26873, ID 2001-032A) from July 31, 2001 (0.1 - 82 MeV) to December 6, 2005 (0.1 - 260 MeV) [5-7]. Some tens of GRBs were observed both short and long types and during some of them high energy emission in the band E>10 MeV was detected [5-7].

At present GRB high energy emission registered by two satellite experiments. The gamma-ray imaging detector (GRID) onboard AGILE [8] operated since the April 2007. It allows bursts observation in the energy band 30 MeV–30 GeV. Some tens of GRBs were registered by AGILE and several percents of detected events had high-energy component. Fermi gamma-ray observatory operated from the June 2008 [9]. It registered ~1690 identified GRBs using GBM in energy band 8 keV-40 MeV [10] and ~100 bursts using LAT from 0.1 GeV up to >300 GeV [11].

2. The additional high-energy component in GRBs energy spectra.

As the results of BATSE experiment onboard CGRO, several models were intended for the gamma-ray bursts energy spectra analysis in the low energy band from several tens of keV up to several MeV. Most part of GRBs energy spectra (both time resolved and time integrated) usually described by two-component Band function where first component is proportional to combination of power law with index α and exponential cut-off defined by $E_{break}=E_{peak}/(2+\alpha)$, while second one is proportional to power law with index β [12]:

$$f_{Band}(E)=\begin{cases} A\left(\frac{E}{100}\right)^{\alpha}\exp\left[-\frac{E(2+\alpha)}{E_{peak}}\right], & \mathrm{E}<\left[\frac{(\alpha-\beta)E_{peak}}{2+\alpha}\right]; \\ A\left[\frac{(\alpha-\beta)E_{peak}}{100(2+\alpha)}\right]\exp(\beta-\alpha)\left(\frac{E}{100}\right)^{\beta}, & \mathrm{E}\geq\left[\frac{(\alpha-\beta)E_{peak}}{2+\alpha}\right]; \end{cases} \tag{1}$$

As it was mentioned above, the high-energy component with E>20 MeV was first observed during GRB 910503 on CGRO/EGRET data. Totally gamma-emission in the range E>120 MeV were registered for 15 GRB on CGRO data [14] but for three GRB E_{max} ~130÷140 MeV and gamma-quanta with E>200 MeV were not detected. The spectral parameters of the most GRBs part were typically decreasing monotonically while the flux rises and falls or its behaviour corresponds to flux temporal profile [7]. Usually this component observed during prompt emission and its beginning is coinciding with low energy emission.

Some GRBs spectra revealed the new spectral component not corresponding to Band model (920902, 941017 and 980923) [15] and the next energy break occurs during these events. GRB 941017 was the typical example of such burst. Spectrum of this burst (see Fig. 1) on BATSE and EGRET data contradicts to Band model in the high-energy region. Second components of Band model (β) for GRB 941017 spectra in various energy regions are shown as dashed lines at this figure. Approximations for high energy part of this burst spectra are shown as grey lines also at Fig.1. The shape of high-energy non-Band component described in the first approximation by power law with index Γ - see, for example, [16]. Let us denote the Band model E_{peak} parameter as E_1 and break energy between the second Band model component and the high-energy additional component as E_2. The difference between these two types of spectral shapes is well seen and both break energies E_1 and E_2 shifted to the low energy region during the burst. The duration of high-energy emission was similar to low energy one for GRBs registered by CGRO. However after GRB 940217 (BATSE trigger #2831, t_{90}=150 s) gamma-quanta with E>50 MeV were registered about 1.5 hours after burst starts (the first extended high-energy emission detection). The energy spectrum of extended episodes is usually described by power law with spectral index similar to Γ of non-Band component. In addition, several low-energy events of extended emission were registered by detectors onboard CGRO [17].

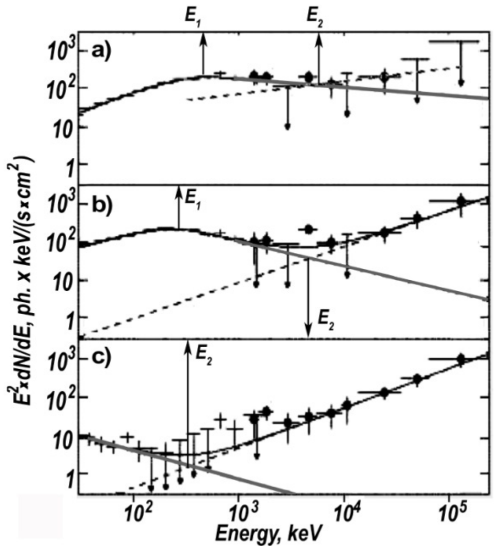

Fig. 1. The GRB 941017energy spectra by BATSE and EGRET data for prompt emission three time intervals since BATSE trigger: a) -18s ÷ 14 s, b) 47 – 80 s, c) 113 – 211 s. Data were taken from [12] and references therein.

In addition, high-energy component were registered on CORONAS-F/AVS-F data during GRB prompt emission too. The common analysis of EGRET and AVS-F databases allows to introduce additional break energy E_2 and conclude that E_2 ~3÷10 MeV [7].

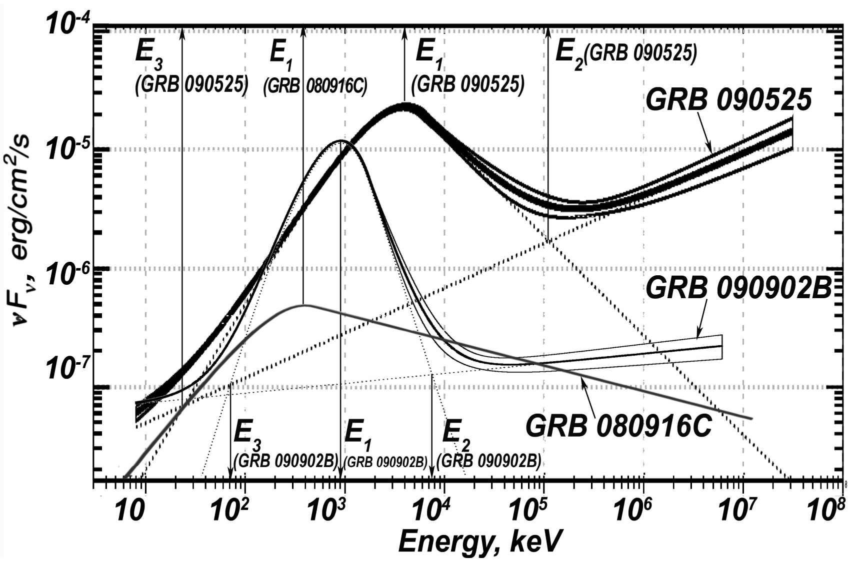

Fig. 2. The prompt emission energy spectra approximations for GRB 080916C (from t_0 +15.87 up to t_0 +54.78 s, t_0=00:12:45.614 UT), GRB 090525 (from t_0 +0.5 up to t_0 +1.0 s, t_0=00:22:59.97 UT) and GRB 090902B (from t_0 +4.6 up to t_0 +9.6 s, t_0=11:05:08.313 UT). Fermi/GBM and Fermi/LAT data were taken from [18, 21, 22].

At present GRB observed in the very wide energy range, for example Band spectrum of GRB 080916C covering 7 decades of energy from ~8 keV up to ~13 GeV with β ~ −2.2 during most part of burst prompt emission [18]. For several GRBs parameter β characterizes the spectral shape in the region up to some hundred MeV. For instance, GRB 100724B is approximated by power law with β ~ −2.13 in the region 0.5 MeV-3.5 GeV on AGILE data [19]. But its real spectral model is Band with Epeak~360 keV and β ~ −2 on Fermi/GBM data [10] and it looks like power law because of E_{peak} is outside of AGILE spectral range for this burst.

BATSE threshold energy was ~10 keV but usually the analyzed spectra considered since ~30 keV [17]. Therefore CGRO provided GRBs observations within 6 decades of energy. Now Fermi/GBM minimal registered energy ~8 keV and the next low-energy spectral break E_3 was found during GRB prompt emission studying – see, for example [7]. This very low-energy spectral component describes by power law with index δ as was introduced in [16]. Therefore E_3 is break energy between region described by Band model and power-law region in the low-energy part of GRB spectrum. The typical illustration of three types of energy breaks on GRBs spectra are shown at Fig. 2 (GRB 090525 and GRB 090902B) in comparison with usual GRB 080916C corresponding to Band model in wide energy range. The detailed studying enable to suppose that single mechanism provide wide range emission during GRB in combination to one corresponds to Band model [21, 22]. The analysis of acceleration mechanisms types and typical duration of produced emission was presented for example in [17, 23, 24].

Table 1. The examples of spectral indexes and time parameters for several GRBs with additional spectral component and extended high-energy emission.

Fermi trigger number of GRB	spectral index				t_{90}, s	Extended high energy emission duration	GCN circular number [16]
	α	β	δ	Γ			
120624B	-0.85	-2.36	-2.7 ±0.3	-2.4±0.2	271	~10^3	13379 13377 13383
091003	-1.13	-2.64	$-1.87(^{+0.15}/_{-0.16})$	-1.85±0.25	21.1	~10^3	9983 9985
090926A	-0.43	-3.00	$-2.153(^{+0.072}/_{-0.071})$	-2.34±0.14	20	2×10^3	9972 9350
090902B	0.6	-3.87	$-2.24(^{+0.25}/_{-0.25})$	-2.32±0.16	21	~10^3	9872
090510	0.11	-1.61	$-1.82(^{+0.15}/_{-0.14})$	-2.15±0.1	0.3	2×10^3	9336
090328	-0.92	-2.30	$-1.82(^{+0.23}/_{-0.31})$	-1.76±0.35	80	6×10^3	9057 9044
090323	-0.96	-2.3	$-1.96(^{+0.24}/_{-0.21})$	-2.05±0.2	150	3×10^3	9030
080916C	-0.91	-2.06	-2.03± 0.43	-2.09±0.12	66	1×10^3	8278

The observed high energy emission duration on Fermi/LAT and AGILE data usually does not depend from burst parameters in low-energy band. The prompt high-energy emission observed during several GRBs – the typical examples are GRB 080916C [18] and GRB 100724B [19]. The first high-energy photons were delayed in both cases for ~3s. However extended high-energy component was registered for both short and long bursts and its duration is from hundreds to several thousands of seconds independently of GRBs t_{90} – see Table 1. The spectral parameters for several GRB with additional component and extended emission appearance are presented in Table 1. This table analysis allows to conclude that GRBs spectral parameter δ (describing X-ray emission in the range E<100 keV) similar to Γ (characterizing gamma-emission in the band E>100 MeV) and the question about wide range emission during GRB formation due to single mechanism arises again.

3. Conclusion

The energy spectra shape of GRBs with high-energy emission presence can follows the Band model (or power law or broken power law) up to some tens or hundreds of MeV (as for GRB 100724B and GRB 021008). Also it is possible to contain additional high-energy power law component (for example GRB 050525B and GRB 090902B).

Both GRBs types were registered since CGRO mission beginning. The analysis of their energy spectra has shown that the break between low-energy spectral part (described by either Band or power law or broken power law etc. models) and additional component was in energy region 2-200 MeV. The Fermi/LAT low-energy threshold is lower than CGRO/BATSE one and very low-energy spectral component is described by power law with index δ and characterising X-ray emission in the range E<50 keV was introduced for several bursts energy spectra approximation. Moreover, for several GRBs this spectral parameter δ similar to Γ (characterizing gamma-emission in the band E>100 MeV) and the question about formation of wide range emission during GRB due to single mechanism arises again.

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